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AN IN-SITU BENTHIC RESPIROMETER

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TABLE OF CONTENTS

	Page
INTRODUCTION	1
RESPIROMETER DESIGN	2
METHOD OF OPERATION	3
INTERPRETATION OF DATA	4
PRELIMINARY RESULTS OBTAINED	6
CONCLUSION	8

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INTRODUCTION

In attempting to describe the oxygen balance of natural waters, it is essential that all significant sources and sinks of oxygen be considered. Oxygen uptake by the bottom muds found in rivers, lakes, and estuaries is such a sink and, in some situations, a most significant one. It's magnitude, however, is usually difficult to evaluate with the desired degree of confidence. Most methods of evaluation in current use require removal of the muds from their natural environment for oxygen uptake measurements in the laboratory. However, it is extremely difficult to reconstruct the natural layering of solids in a laboratory flask, which would appear to be a necessary condition for obtaining realistic results. In addition, the interstitial water in bottom sludges is likely to contain soluble constituents having a high oxygen demand, and these materials may be lost or diluted in collecting the sludge sample. The quality of water overlying the sludges may also influence oxygen uptake rates in the natural environment. For these reasons a benthic respirometer capable of measuring the oxygen uptake rates of bottom muds in-situ is highly desirable. Such a device has been developed and is described below.

RESPIROMETER DESIGN

The operating principle of the respirometer is to trap and confine a volume of overlying water in contact with the bottom while observing any reduction in dissolved oxygen content resulting from uptake by the bottom muds. The apparatus shown schematically in Figure 1 was designed to accomplish this purpose. The respirometer chamber was constructed from a 21-inch length of 19-inch diameter metal pipe having a 1/16-inch wall thickness and a flange on both ends. The pipe was cut lengthwise along its centerline, creating two sections--each of which could serve as a shell of a respirometer chamber. The semi-circular ends were closed with metal plates, and a 4-inch right angle metal section was attached around the periphery of the 19-inch by 21-inch rectangular opening, providing a vertical cutting edge and a horizontal supporting ledge. A lifting ring and a submersible 12-volt pump were attached to the exterior of the curved top surface. A hole was drilled through the top of the respirometer to receive the pump intake line, while the pump discharge was conducted by a length of plastic tubing to a flexible 4-liter rubber bag. Another piece of plastic tubing connects this bag to the respirometer chamber, entering through a port in the end wall. The presence of the flexible bag permits the removal of samples from the system without the necessity for replacement of an equivalent volume of water.

The respirometer chamber joints were sealed with sheet rubber gasket material to prevent leakage, and all metal surfaces were coated

with an epoxy paint before assembly to minimize the possibility of corrosion accompanied by oxygen loss. All elements of the system were made impervious to light to eliminate possible photosynthetic effects.

METHOD OF OPERATION

The respirometer is lowered through the water from a pier or boat using the lifting ring. The submersible pump, powered by a battery at the water's surface, is operated while the chamber is lowered, so as to empty it of the surface water originally present. The chamber is lowered to within a foot of the bottom and held there for a few minutes while the pump draws bottom waters into the chamber and tubing. The pump discharge tubing is then connected to the flexible bag from which the flow is returned to the respirometer. The recirculating system may be purged of air through the sampling port located in the tubing line at the surface. The respirometer is then lowered carefully to the bottom. The weight of the chamber (approximately 28 pounds) forces the cutting edge into the bottom, while the supporting ledge prevents the chamber from sinking below the sediment surface.

The pump is run continuously throughout the test, providing continuous mixing of the water in the chamber. The pump discharge rate may be varied to simulate the degree of turbulence believed to exist at the water-bottom interface. Since the water pumped from the chamber is recirculated, no significant change in the volume of pressure of the chamber contents will occur.

The test period begins when samples are initially taken from the sampling port at the surface for dissolved oxygen analyses. Duplicate 300 ml samples are collected for immediate analysis, while another pair of samples are withdrawn into dark bottles which are incubated in the water during the period of the test. Another pair of samples are withdrawn at the end of the test period. Dissolved oxygen is measured in this final pair and in the incubated dark bottles.

As an alternate to this method of operation, a dissolved oxygen probe may be inserted into the recirculation system. The use of a probe would permit continuous measurements to be taken without the necessity for removing samples from the system. The flexible bag and sampling port shown in Figure 1 could be eliminated.

With either of these measurement systems, it is clear that some dissolved oxygen must be initially present in the water overlying the bottom in order to conduct a test. Where anaerobic waters are encountered, the approach described could be modified so as to artificially introduce oxygenated waters into the respirometer.

INTERPRETATION OF DATA

The difference between the initial and final dissolved oxygen concentrations observed in the respirometer is directly related to oxygen uptake by the bottom. This change in concentration may be expressed as an areal uptake rate (S) if the confined water volume (V) and bottom area (A) are known. In the expression:

$$S\ (gm/m^2/day) = \frac{(C_i - C_f)\ V}{t\ A} \qquad (1)$$

t is the test period in days; C_i and C_f are, respectively, the initial and final observed dissolved oxygen concentrations (as milligrams per liter or grams per cubic meter), and V and A are expressed in metric units, being 0.043 m^3 and 0.276 m^2, respectively, for the respirometer previously described. The oxygen concentrations of the incubated dark bottles, as determined at the end of the test period, may be substituted in equation (1) for C_i if a significant difference exists between these values. This difference represents oxygen uptake of the waters overlying the bottom and will usually be negligibly small for a short test period.

The length of test period required depends both on the size of the respirometer and the uptake rate being measured. A minimum oxygen change of 1 mg/l is considered desirable for reliable results, and this also influences the test period length. For the respirometer described above, the length of test required to give a 1 mg/l oxygen change is given as a function of uptake in Figure 2.

In order to minimize the length of the test period, the ratio of confined volume to bottom surface area or the effective depth should be minimized. This consideration influenced the respirometer design adopted, in that the semi-circular cross-section of the chamber has a relatively low volume:area ratio. The effective depth of this cross-section is $\frac{\pi}{4}$ or 0.784 times the radius of the semi-circle.

The units used to express the areal uptake rate (grams/square meter/day) can be readily converted to volumetric units by dividing S by the depth of the overlying water in meters. This quotient has the units $gm/m^3/day$, or mg/liter/day, and refers to the DO change expected in the full depth of the water due to the oxygen sink at the bottom.

PRELIMINARY RESULTS OBTAINED

The benthic respirometer shown in Figure 1 was used to measure bottom uptake rates in the Potomac estuary near Washington, D. C., during August and September, 1965. A total of 25 tests were carried out in a twenty-mile length of the estuary. Uptake rates from 0.15 to 8.5 gms/square meter/day were found at water temperatures in the range of 22.5 to 33 degrees centigrade. To provide a basis for studying the longitudinal variation in uptake rates along the estuary, the results were converted to a common temperature of 25°. The temperature correction factor of 6.5 per cent per degree centigrade, as determined by Fair[1] for benthal decomposition, was used. At this common temperature, the adjusted uptake rates averaged 2.5 gms/square meter/day. Slightly higher values were usually found near the main waste source, and rates below 1 gm/square meter/day were found at distances five miles above and fifteen miles below this location.

Since there is no known method for absolute measurement of in-situ benthal oxygen demands, it is not possible to make any statement regarding the accuracy of the measurements obtained using the

benthic respirometer. The magnitude of the rates observed, however, generally fall within the range of those believed to exist in natural water subject to pollutional loads. O'Connor[2], for example, states that typical values range from 1 to 10 grams/square meter/day with the majority of values lying between 3 to 5 grams/square meter/day for relatively polluted streams. These conclusions were apparently based both on laboratory studies and analyses of field stream survey data.

Certain operational difficulties were encountered in using the benthic respirometer. These were generally associated with disturbing the surface sediment layer and led to anomalous test results. It was found that the respirometer must be brought into contact with the bottom very carefully, to avoid putting any of the settled solids into suspension.

The water recirculation rate used in the Potomac tests was estimated from measurements of the time required to fill a sample bottle of known volume through the sampling port at the water surface. The approximate horizontal velocity over the bottom muds confined by the chamber was calculated from this flow rate to be less than 0.5 feet per minute. Such a velocity is not believed to be sufficient to unduly agitate the surface sediment layer. This conclusion was supported by the absence of unusual amounts of suspended material in the water samples removed from the system for oxygen analyses during the tests.

An initial concern in the operation of the respirometer was whether an effective seal with the bottom could be obtained. This is essential to prevent the exchange of the oxygen-depressed chamber contents with the surrounding waters. To investigate this condition, samples of unconfined water were routinely collected near the respirometer at the beginning and end of a test. Changes in dissolved oxygen content occurring within the respirometer were not reflected in the external samples, and differences greater than 1 mg/l between the two samples were frequently observed at the end of a test. It was concluded that for the particular respirometer and bottom mud characteristics of these tests, an effective seal was obtained. The weight of the respirometer shown in Figure 1, being 38 pounds in air, undoubtedly was an important factor in maintaining this condition throughout a test.

CONCLUSION

Preliminary field tests of an in-situ benthic respirometer yielded reasonable results which are believed to be a satisfactory measure of the benthal oxygen demands actually occurring in the waters studied. Further tests of this measurement technique under a variety of conditions would be desirable to determine more precisely its reliability and general applicability.

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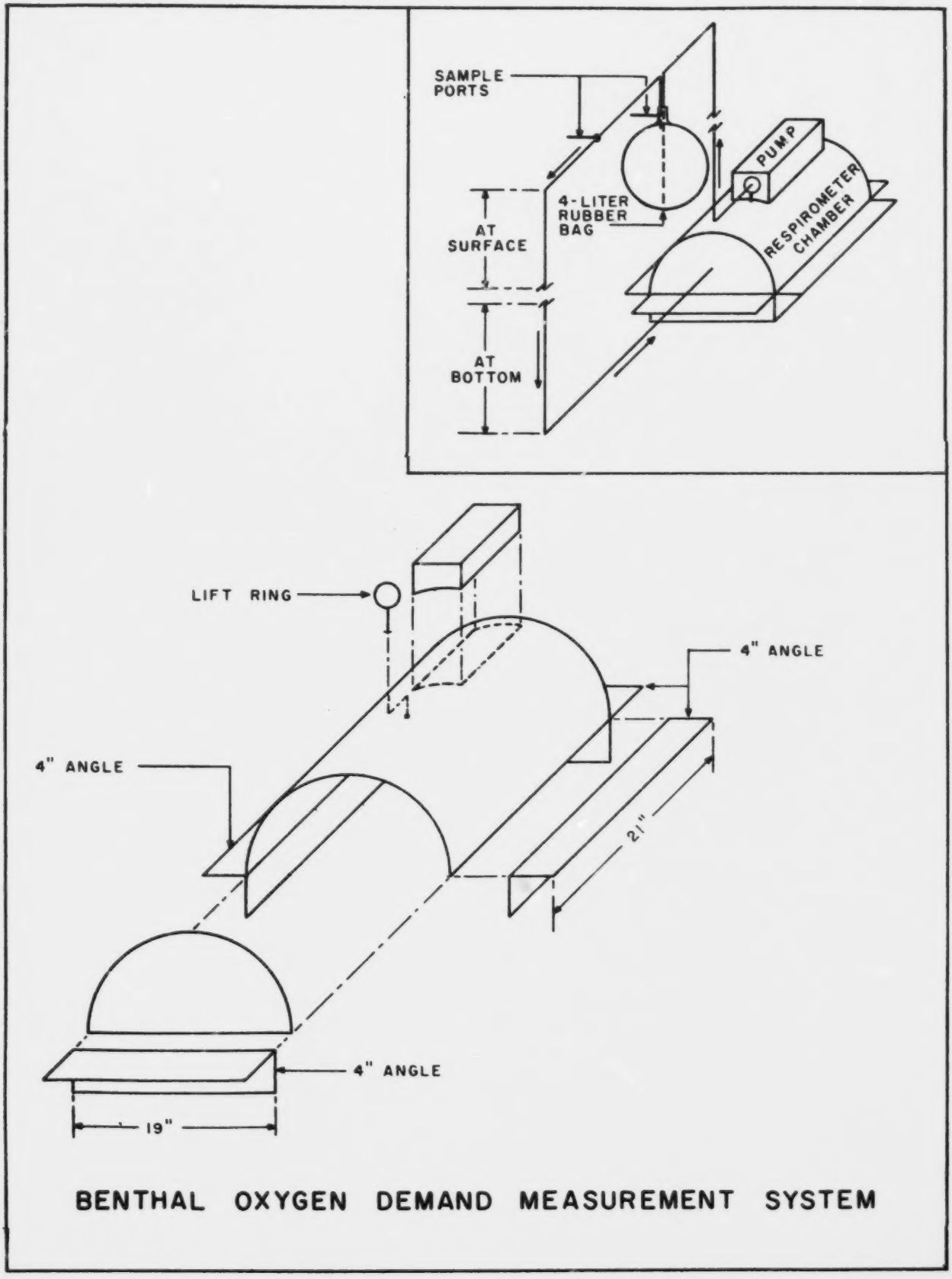
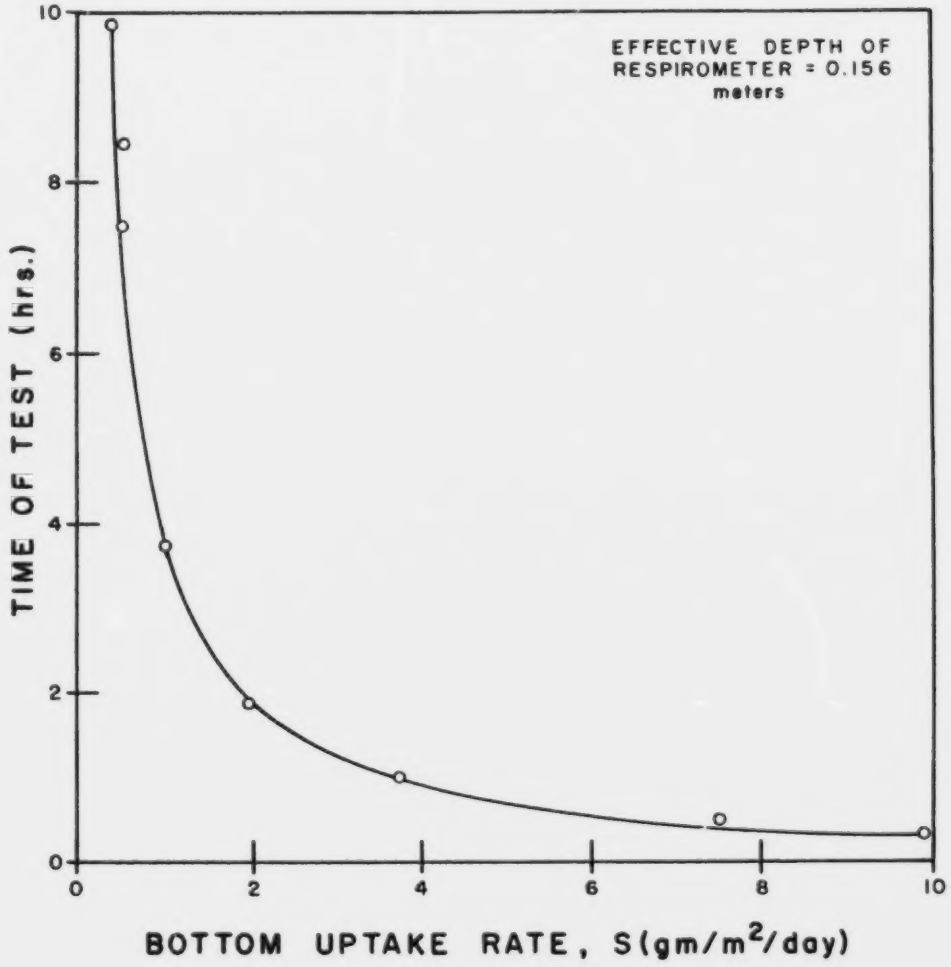


BENTHAL OXYGEN DEMAND MEASUREMENT SYSTEM

FIGURE 1



TEST PERIOD REQUIRED FOR 1ppm D.O. DROP

FIGURE 2